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DETERMINATION FROM FLIGHT TESTS OF THRUST COEFFICIENTS FOR 10 FULL-SCALE AIRPLANES IN THE GLIDING CONDITION WITH ENGINE IDLING

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DETERMINATION FROM FLIGHT TESTS OF THRUST COEFFICIENTS FOR 10 FULL-SCALE AIRPLANES IN THE GLIDING CONDITION WITH ENGINE IDLING

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SUMMARY

Typical thrust and torque coefficients and increments, due to the propeller, in the ratio of the dynamic pressure at the tail to the free-stream dynamic pressure $\Delta\left(\frac{q_t}{q_o}\right)_{prop}$ are presented for 10 full-scale airplanes. These quantities were calculated from flight measurements of engine speed and airspeed with the aid of propeller charts to provide thrust data to serve as a basis for the simulation of gliding-flight conditions of full-scale airplanes on powered wind-tunnel models. The thrust coefficient T_c ranged from values of about 0 to -0.1 with an average value of -0.035 at a lift coefficient of 0.5. Values of $\Delta\left(\frac{q_t}{q_o}\right)_{prop}$ estimated from the propeller thrust coefficient ranged from 0 to about -0.20 with the average at about -0.09 at low lift coefficients. The thrust and torque coefficients consistently became slightly more negative as the speed decreased. Calculations indicate that an error of about 2 percent mean aerodynamic chord appears possible in determining the neutral point from wind-tunnel tests of a model in the gliding condition if the propeller is operated at zero thrust rather than at the values of thrust coefficient indicated by the flight tests.

INTRODUCTION

An idling propeller generally has an important effect on the longitudinal stability of an airplane because of the moments contributed by the thrust and the vertical forces acting on the propeller and because of the effects on downwash and dynamic pressure at the tail. For conventional airplane arrangements, the net effect is usually destabilizing. In order to predict correctly the stability of an airplane in the gliding condition from wind-tunnel tests, the thrust coefficients at each lift coefficient should be equal to the actual thrust coefficient on the full-scale airplane.

In testing powered models in wind tunnels, the present general procedure in simulating the gliding condition (engine idling) is to operate at a thrust coefficient equal to 0 or to let the propellers windmill. In the past, data on the values of thrust and torque coefficients of full-scale airplanes in the gliding condition have not been available. The purpose of this report is to present typical thrust and torque coefficients for full-scale airplanes in order that an attempt to reproduce them on powered models can be made.

SYMBOLS

C_L	lift coefficient $\left(L/q_oS\right)$
C_T	thrust coefficient $\left(T/\rho n^2D^4\right)$
C_P	power coefficient $\left(P/\rho n^3D^5\right)$
T_c	thrust coefficient $\left(\frac{T}{\rho V^2D^2} \text{ or } \frac{C_T}{J^2}\right)$
Q_c	torque coefficient $\left(\frac{Q}{\rho V^2D^3} \text{ or } \frac{C_P}{2\pi J^2}\right)$
J	advance-diameter ratio (V/nD)
$\Delta\left(\frac{q_t}{q_o}\right)_{prop}$	increment in ratio of dynamic pressure at tail to free-stream dynamic pressure due to propeller $\left(\frac{8T_c}{\pi}\right)$
L	lift
q_o	free-stream dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

q_t	dynamic pressure at tail
S	wing area
T	effective thrust
P	engine power
Q	torque
ρ	mass density of air
n	propeller speed
D	propeller diameter
R	propeller radius
V	true airspeed

TEST AND RESULTS

Flight tests were made of 10 full-scale airplanes with constant-speed propellers. The airplanes were flown with flaps up, landing gear up, and engines idling; the airspeed, the engine speed, and the altitude were recorded from the speed at which the propeller was governed to the stalling speed. The pertinent details of the engine-propeller combination for each airplane are given in table I.

The airspeed was measured with an airspeed indicator in the cockpit connected to the service airspeed installation, except for airplane 5 and airplane 7, in which the airspeed indicator was connected to the NACA airspeed installation. Calibrations for the airspeed indicators were available for only five airplanes but in these cases the errors introduced by using the uncorrected indicator reading were found to be small. The altitude was measured by an indicating altimeter and the engine speed by an indicating tachometer. Only readings taken with the airplane in steady conditions were used in order to avoid errors in the engine speed. The blade angles of the propellers in the low-pitch position were measured to an accuracy of $\pm 0.2^\circ$ by means of a propeller protractor.

Although the propellers were of the constant-speed type, the blades were against the low-pitch stop in the speed range tested and the propellers therefore behaved like propellers with fixed pitch.

From the measured values of advance-diameter ratio and blade angle, the thrust coefficient C_T and the power coefficient C_P were obtained from propeller charts. The charts used included only positive values of thrust and power and small extrapolations were necessary to obtain the negative values that were usually encountered in the gliding condition. For the Hamilton Standard propeller-blade design 6101A-12 used on airplane 1 and airplane 2, the thrust coefficient C_T and the power coefficient C_P were obtained from the propeller charts for blade design 6101 in reference 1. The coefficients C_T and C_P for the Hamilton Standard propeller-blade design 6443A-21, which has a Clark Y section at the root and an NACA 16-series airfoil section at the tip, were obtained from unpublished charts for a propeller with this type of blade prepared at the Langley propeller-research tunnel. All other propellers had Clark Y sections throughout and the coefficients were obtained from unpublished charts for a propeller with this type of blade. In reference 1 the propeller was tested with a radial engine nacelle; all other propellers were tested with a small streamline nacelle.

No corrections for body interference were applied in obtaining the coefficients for the full-scale airplanes; corrections were applied, however, for the differences in the activity factor by multiplying the thrust and torque coefficients obtained from the charts by the ratio of the activity factor of the propeller tested to that used in the chart. The coefficients C_T and C_P were transformed to the thrust coefficient T_c and the torque coefficient Q_c, respectively, and the increment in the ratio of the dynamic pressure at the tail to the free-stream dynamic due to the propeller $\Delta\left(\frac{q_t}{q_o}\right)_{prop}$ was determined by the equation:

$$\Delta\left(\frac{q_t}{q_o}\right)_{prop} = \frac{8T_c}{\pi}$$

In order to get the total q_t/q_o the effect of the fuselage and wing wake, which was not measured, must be included. The variation of the quantities T_c, Q_c, and $\Delta\left(\frac{q_t}{q_o}\right)_{prop}$ with C_L is given for each airplane in figures 1 to 10.

DISCUSSION

The thrust coefficient T_c was generally negative at low lift coefficients and became more negative at higher lift coefficients. For the airplanes tested, the range of thrust coefficients was approximately 0 to -0.1; the average value at a lift coefficient of 0.5 was about -0.035. The variation of the torque coefficient Q_c was similar to the variation of the thrust coefficient T_c, in that both became more negative at higher lift coefficients.

The increment of the ratio of the dynamic pressure at the tail to the free-stream dynamic pressure due to the idling propeller $\Delta\left(\frac{q_t}{q_o}\right)_{prop}$ ranged from 0.01 to -0.22; the average value for all airplanes at a low lift coefficient was about -0.09. These increments for airplanes 2, 4, and 7 were greater than -0.12 throughout the range of lift coefficient. These unusually large increments may be shown to result in an appreciable reduction in longitudinal stability. The effect on the longitudinal stability of the variation of dynamic pressure at the tail with lift coefficient is usually small for the gliding condition with flaps retracted and may be neglected for preliminary estimates.

Calculations were made to determine the difference in stability that would be expected to result if a wind-tunnel model were tested in the gliding condition with the measured values of thrust coefficient instead of with zero thrust coefficient. The thrust coefficients measured on airplane 6 (fig. 6) were taken as typical of the results obtained. The change in neutral point between the conditions of zero thrust and the measured thrust coefficient was estimated from the effects of the changes in thrust force, propeller vertical force, and downwash and dynamic pressure at the tail.

The thrust forces affect the neutral point if the thrust coefficient varies with lift coefficient. The effect is proportional to the distance between the center of gravity and the thrust axis. For airplane 6, the effect of the variation of thrust coefficient with lift coefficient was negligible because the center of gravity of the airplane was very close to the thrust axis; on an airplane of which the center of gravity was 0.1 chord length below the thrust axis, this effect would cause a forward shift in neutral point of about 1 percent mean aerodynamic chord (M.A.C.).

The propeller vertical force and downwash in the slipstream were estimated from the curves given in reference 2. A rearward shift in the neutral point of 0.1 percent M.A.C. due to the vertical force on the propeller was found to be caused by a change in thrust coefficient from 0 to the measured value of -0.042. With the same change in thrust coefficient, the shift in neutral point due to the downwash behind the propeller and the dynamic pressure at the tail was about 1 percent M.A.C. forward. An error of about 2 percent M.A.C. in the determination of the neutral point in the gliding condition therefore appears possible if the propeller-operating conditions are not simulated correctly.

CONCLUSIONS

Results of flight tests made to determine the thrust coefficients of 10 airplanes in the gliding condition with engines idling indicated the following conclusions:

1. The average thrust coefficient measured was -0.035 at a lift coefficient of 0.5.

2. The thrust and torque coefficients became slightly more negative as the speed decreased.

3. At a lift coefficient of 0.5, the average increment of the ratio of dynamic pressure at the tail to free-stream

dynamic pressure due to the idling propeller was about -0.09, which resulted in a loss in longitudinal stability.

4. Calculations indicated that operating at zero thrust instead of correctly simulating the propeller-operating condition in wind-tunnel tests to determine longitudinal stability in the gliding condition may cause a possible error in the calculated neutral point of about 2 percent mean aerodynamic chord.

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REFERENCES

1. Biermann, David, and Hartman, Edwin P.: Tests of Five Full-Scale Propellers in the Presence of a Radial and a Liquid-Cooled Engine Nacelle, Including Tests of Two Spinners. NACA Rep. No. 642, 1938.

2. Ribner, Herbert S.: Notes on the Propeller and Slipstream in Relation to Stability. NACA ARR No. L4I12a, 1944.

TABLE I

DETAILS OF PROPELLER-ENGINE COMBINATIONS OF AIRPLANES TESTED

Airplane	Engine		Propeller		Number of blades	Gear ratio	Propeller diam. (ft)	Low-pitch blade angle at 0.75R (deg)	Blade section	Figure
	Manufacturer	Designation	Manufacturer	Blade design						
1	P & W	R-1340-AN-1	Hamilton Standard	6101A-12	2	1:1	9.0	11	Clark Y	1
2	Wright	R-1820-38	Hamilton Standard	6101A-12	3	1:1	9.0	13	Clark Y	2
3	Wright	R-1820-40	Curtiss	512Cc1.5-9	3	3:2	10.25	21.5	Clark Y	3
4	Wright	R-2600-8	Hamilton Standard	6359A-12	3	16:9	13.0	14.05	Clark Y	4
5	Allison	V-1710-39	Curtiss	89301-3	3	2:1	11.0	20.4	Clark Y	5
6	Wright	R-2600-8	Curtiss	89324-12	3	16:9	12.0	15.5	Clark Y	6
7	P & W	R-2800-10	Hamilton Standard	6501A-0	3	2:1	13.08	17.8	Clark Y	7
8	P & W	R-2800-8	Hamilton Standard	6443A-21	3	2:1	13.33	15.8	Clark Y root, NACA 16-series tip	8
9	Allison	V-1710-39	Curtiss	614Cc1.5-18	3	2:1	10.5	20.2	Clark Y	9
10	P & W	R-2800-21	Curtiss	714-1C2-12	4	2:1	12.16	21.3	Clark Y	10

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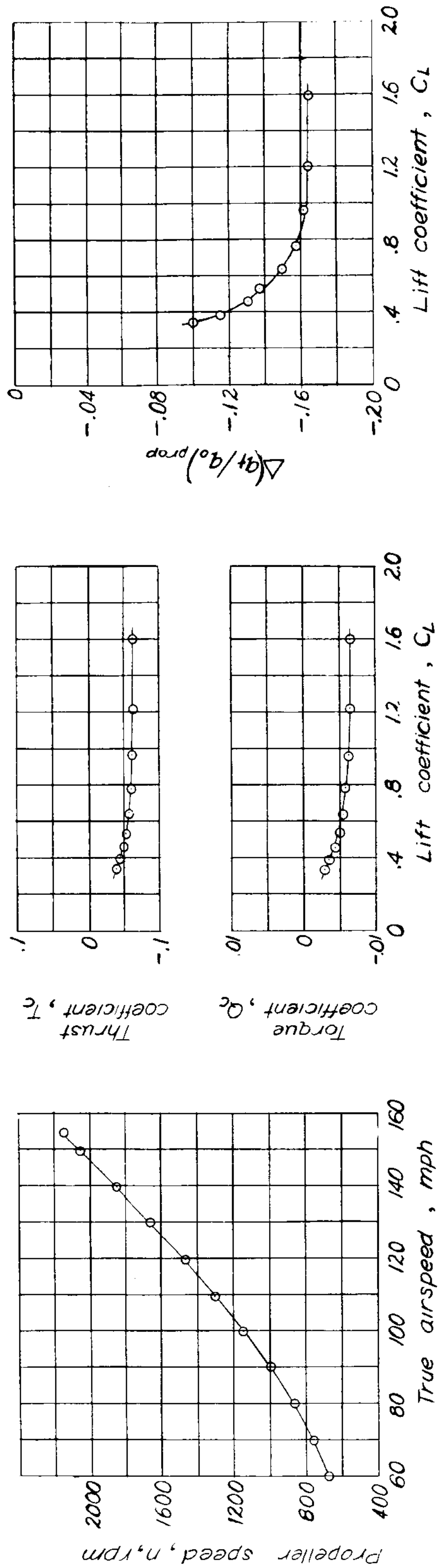

Figure 1. - Airplane 1.

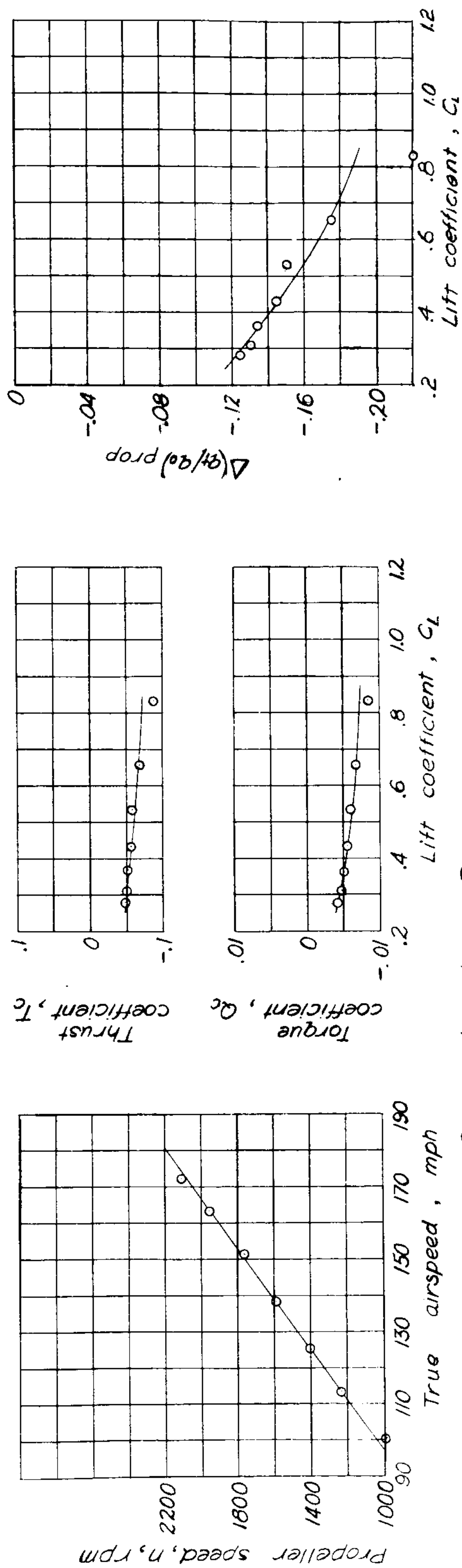

Figure 2. - Airplane 2.

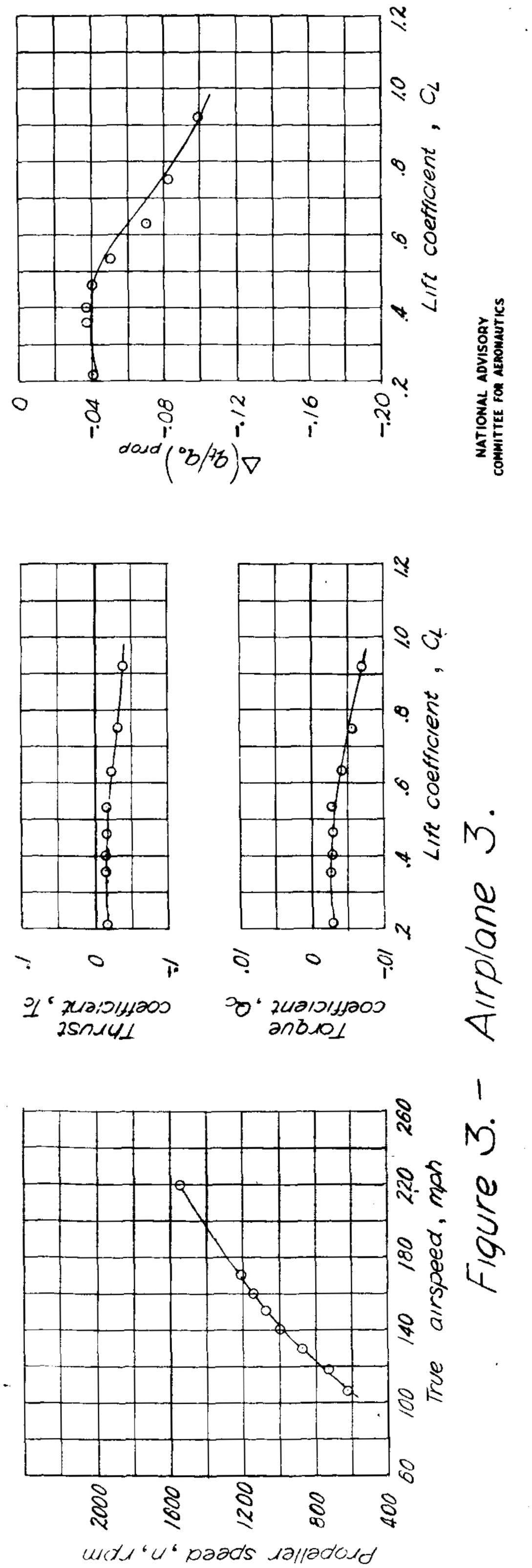

Figure 3.- Airplane 3.

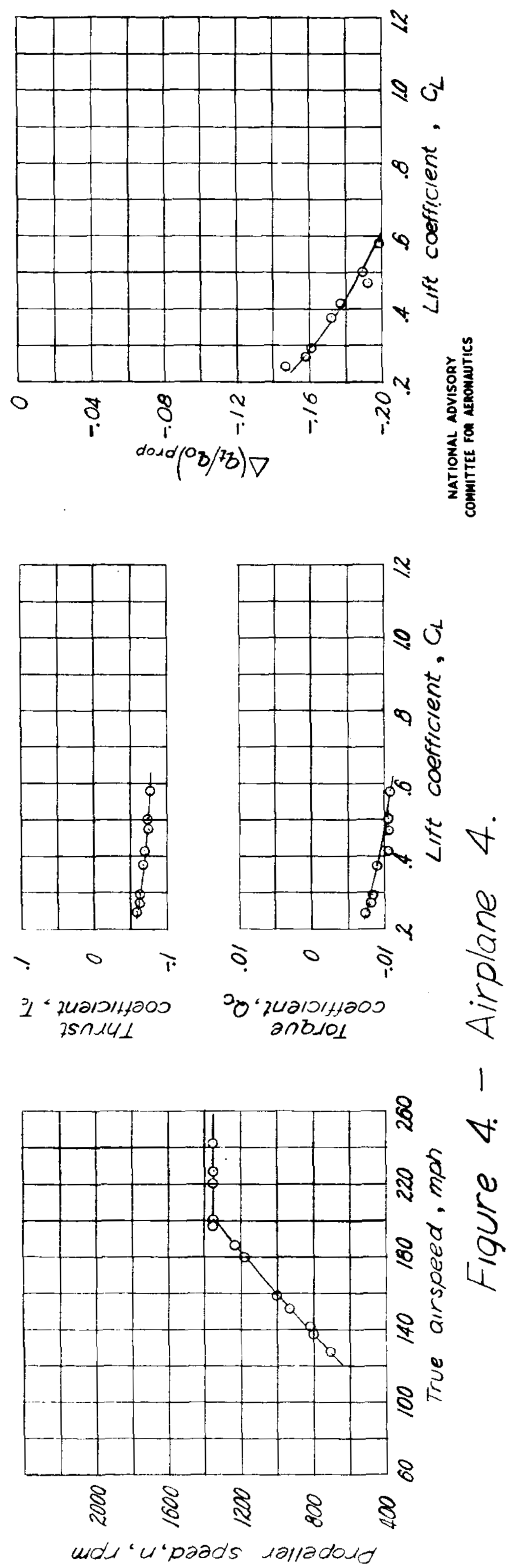

Figure 4.- Airplane 4.

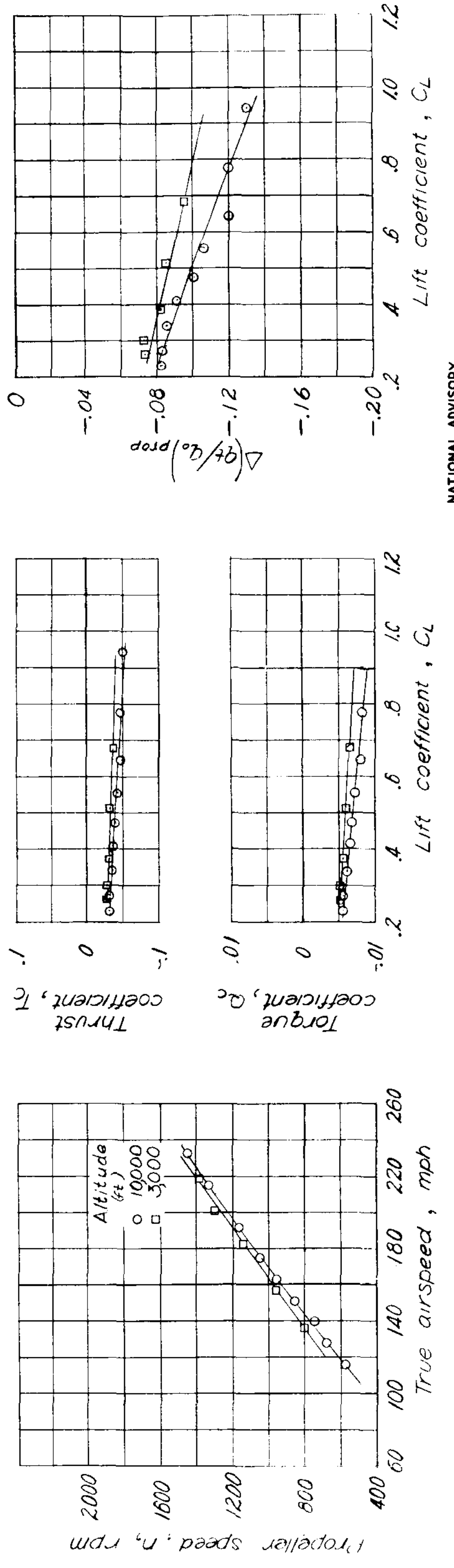

Figure 5.- Airplane 5.

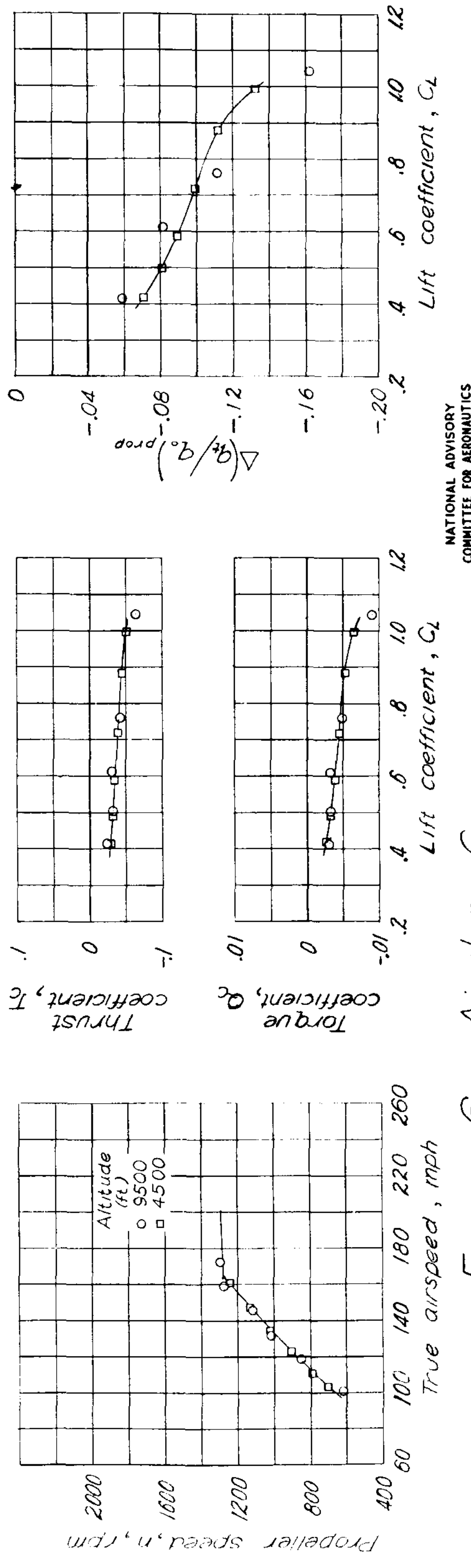

Figure 6.- Airplane 6.

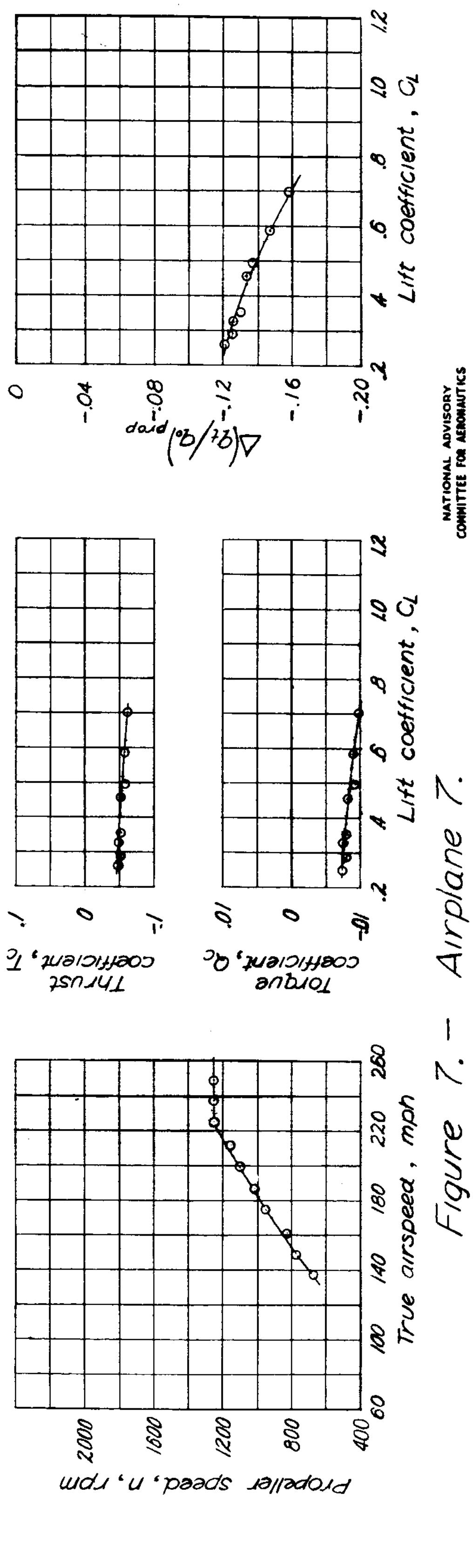

Figure 7.- Airplane 7.

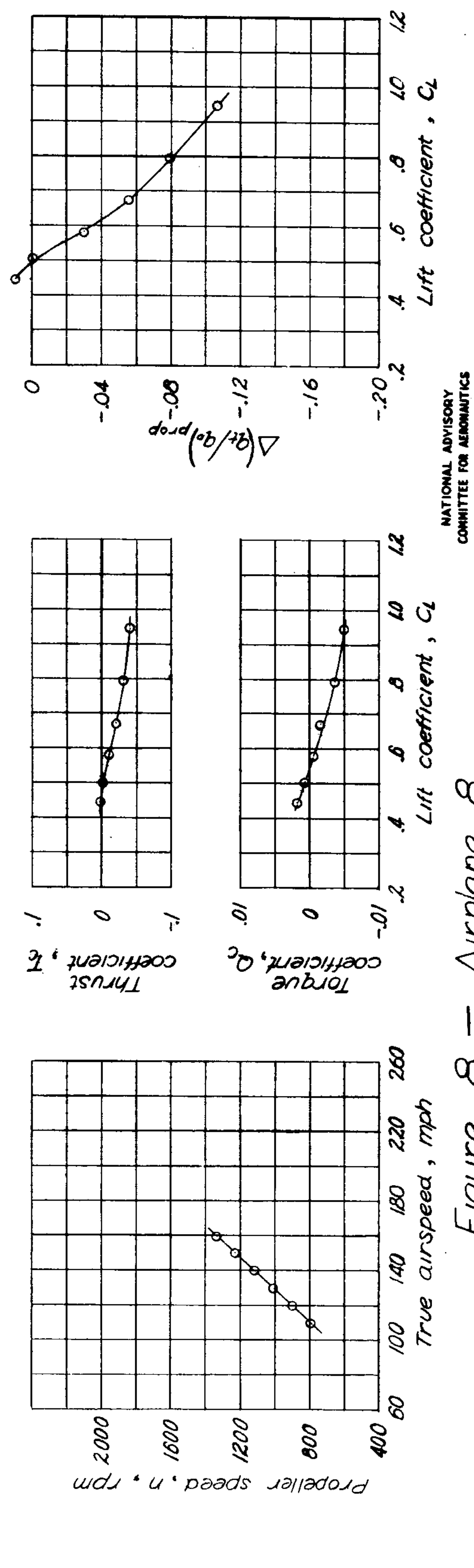

Figure 8.- Airplane 8.

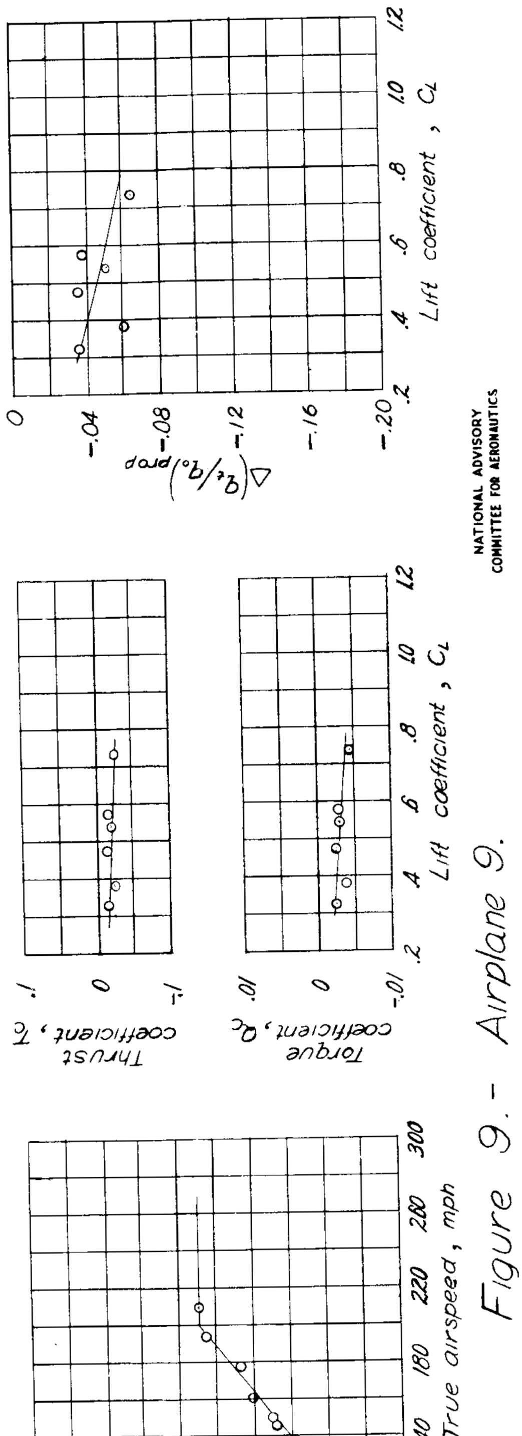

Figure 9.- Airplane 9.

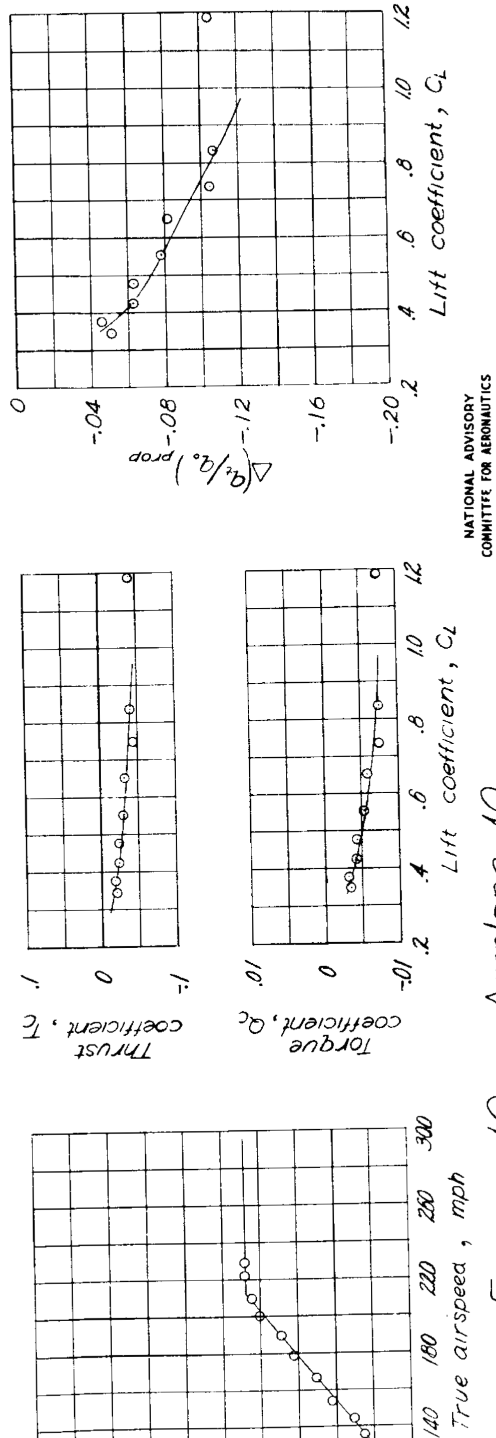

Figure 10.- Airplane 10.